New Improved Technique to Measure Photoreflectance

M. Pamplona Pires
Departamento de Física, Pontifícia Universidade Católica do Rio de Janeiro
Cx.Postal 38071, 22453-900, Rio de Janeiro, RJ, Brazil

P. L. Souza and J. P. von der Weid
Centro de Estudos em Telecomunicações, Pontifícia Universidade Católica do Rio de Janeiro
Rua Marques de São Vicente 225, 22453-900, Rio de Janeiro, RJ, Brazil

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In this work we propose a novel and simple solution to solve some common photoreflectance measurement problems. This new procedure to measure the photoreflectance from a sample surface consists in modulating both pump and probe beams. The probe beam is modulated at a higher frequency ($f_{\rm Probe}$) than the pump beam ($f_{\rm Pump}$) in such a way that the probe beam acts as a carrier for the modulation. The reflected signal is filtered at $f_{\rm Probe}$ and only then it is measured with a lock-in amplifier at $f_{\rm Pump}$. This allows only the modulation of the crystal reflectance to be detected. Consequently, other undesirable reflectance and photoluminescence signals are eliminated even for extremely low probe intensity.

I. Introduction

The development of $GaAs/Al_xGa_{1-x}As$ heterostructures devices has made the study of these materials extremely important. Analysis and design of these structures for different purposes require knowledge of different optical properties. Optical techniques are extremely powerful tools for studying the fundamental nature of these materials. Photoreflectance[1,2] (PR), a contact less form of eletro-modulation[3,4], is one of these techniques. The derivative nature of the modulation suppresses undesirable background effects and emphasizes structures localized in the energy region of inter-band transitions.

A PR experiment consists in measuring the reflectance of a probe light source while a modulated optical perturbation (pump laser beam) modifies the optical properties of the material. A standard photoreflectance spectrum depicts the normalized intensity of the reflectance variation ($\mathbf{\Delta R/R}$) at the perturbation frequency $f_{\rm pumb}$ as a function of the probe wavelength $\lambda_{\rm Probe}$. In semiconductors, the PR signal ranges from 10^{-6} to 10^{-2}. This measurement is made by a phase-sensitive detector (lock-in amplifier) locked at $f_{\rm pump}$. This synchronous measurement contains every signal that is at $f_{\rm pump}$, including diffuse reflected light and photoluminescence (PL), both produced by the pump beam. The latter problem is very significant at low temperatures. In order to circumvent these problems different normalization procedures have already been developed[1,2,5]. In this work we intend to present a novel and simple technique to avoid diffuse reflected light and PL signals.

II. The double modulation technique

This technique consists in modulating both pump and probe beams. As indicated in Fig. 1 the incident light on the sample is composed of pump and probe beams. The major difference from typical PR measurements is that in this experiment the probe is also modulated and this modulation has a frequency $f_{\rm probe}$, higher than $f_{\rm pump}$. As usual, after reflecting on the sample surface, the probe is modulated by the pump at $f_{\rm pump}$. Therefore, the reflected probe beam is then dou-

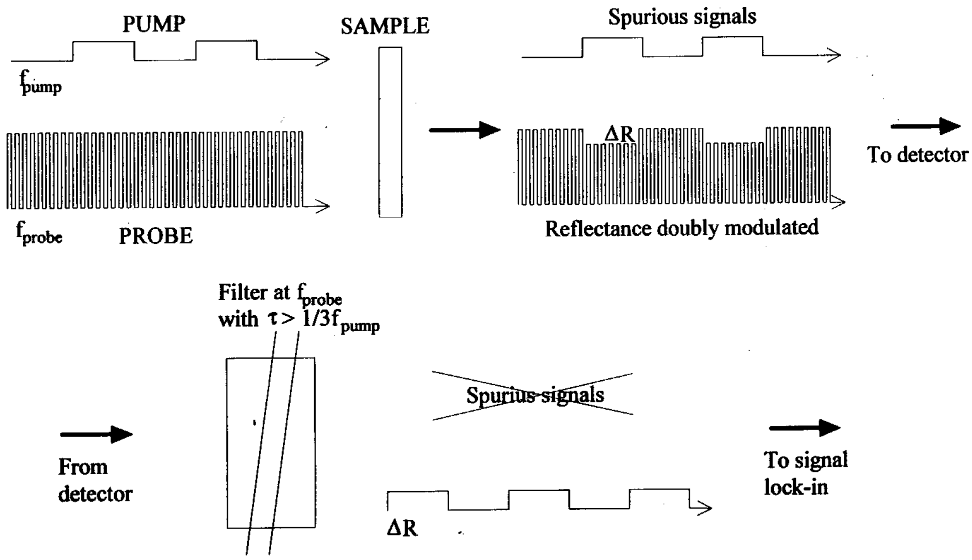

Figure 1. Method to eliminate spurious signals from $\Delta\mathbf{R}/\mathbf{R}$.

bly modulated. The modulation at $f_{\rm pump}$ is the property of interest, namely, the variation of the reflectance ($\Delta\mathbf{R}$) due to carriers created by the pump.

As shown in Fig. 1, the emergent signal from the sample which arrives in the detector contains the reflected probe light and spurious signals (diffuse reflected light and PL). The main idea is to separate the variation in reflectance from the spurious signals. As stated above, emerging from the sample, the reflectance is doubly modulated: first by the modulation of the probe source $f_{\rm probe}$ and second by the pump source $f_{\rm pump}$. Meanwhile, the undesirable spurious signals, which should be eliminated, are modulated only at $f_{\rm pump}$. As shown in Fig. 2 a filter which allows only the signals at $f_{\rm probe}$ to pass is located between the detector and the lock-in *(signal lock-in)*. This filter is, in fact, another lock-in amplifier locked at $f_{\rm probe}$ with a time constant lower than a third of $1/f_{\rm pump}$. This *'filter lock-in'* measures the reflected probe rms signal at $f_{\rm probe}$. Then, in principle, undesirable signals which are modulated at $f_{\rm pump}$ should not go through it. In order to verify the efficiency of this filter we have performed a measurement of the undesirable signal alone. Since the spurious signals occur due to the pump beam, we have switched off the probe beam and kept only the pump beam on the sample. We have verified, by this means, that the signal modulated at $f_{\rm pump}$ which succeeded in passing the filter lock-in was attenuated by 20dB. This high attenuation confirms the effectiveness of the *filter lock-in* in eliminating all spurious signals.

Once the spurious signals are cut off the next step is the determination of $\Delta\mathbf{R}/\mathbf{R}$. In order to accomplish that, part of the output of the *filter lock-in* goes to the A/D converter giving the amplitude of the reflected probe light $(\mathbf{R})$. The other part of the output goes to the *signal lock-in* where it is finally measured synchronously at the perturbation frequency $f_{\rm pump}$. The output of the *signal lock-in* gives the reflectance variation $\Delta\mathbf{R}$, and is also measured by the A/D converter. It is worth noting that it was possible to obtain $\Delta\mathbf{R}$ by this procedure only because the time constant of the *filter lock-in* amplifier is sufficiently small allowing the $\Delta\mathbf{R}$ signal to pass. Using this technique we have been able to obtain directly $\Delta\mathbf{R}/\mathbf{R}$ eliminating undesirable signals. It should be pointed out that to verify the effectiveness of this technique, we performed a point by point measurement of these undesirable signals and subtracted from the conventional $\Delta\mathbf{R}/\mathbf{R}$ signal. The data thus obtained was exactly the same as the one obtained by this new technique. It is worth mentioning that the improvement of this technique resides in eliminating the spurious signal and not in increasing accuracy or sensitivity.

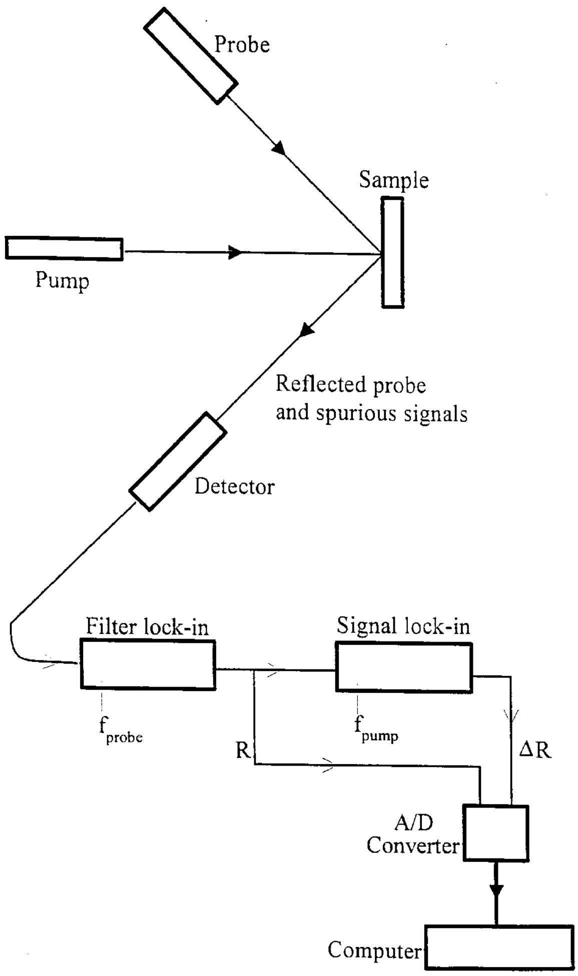

Figure 2. Scheme of the experimental setup.

III. Results and discussion

At first sight this new technique would appear to be just an improvement of the photoreflectance measurement. However, in some special experimental conditions this novel technique could be fundamental. When either the probe intensity is low compared with the spurious signals or the PL signal varies due to temperature-changes, the measurement of $\Delta\mathbf{R}/\mathbf{R}$ can not be performed with a conventional set-up. In such a situation a distinct arrangement is required. An example is the beat time-resolved technique (BTR) which was described in detail elsewhere[6].

When a semiconductor laser gain-switched is used as a probe light source for the BTR experiment, the probe signal is inconveniently low. In addition, the ratio of the gap energy (E_g) with the probe energy (E_0) is varied by changing the temperature, and consequently E_g and not by modifying E_0 through a change in the probe wavelength (λ_{probe}). Changing the temperature of the experiment implies in a change of the PL signal for each data point. So, under these conditions, we have both a varying PL signal and a low probe intensity. These experimental conditions are extremely critical. The $\Delta\mathbf{R}/\mathbf{R}\times E_g/E_0$ is measured by modifying the temperature, as mentioned above, and this changes the PL intensity at each point of the spectrum. A simple subtraction of the PL signal is extremely tedious because this means that it would be necessary to measure the PL intensity at each data point. Using the double modulation technique in a BTR experiment makes it possible to measure the $\Delta\mathbf{R}/\mathbf{R}\times E_g/E_0$ spectrum eliminating the PL signal naturally.

The sample, grown by metalorganic vapor deposition, consists of an undoped 1 μm thick $Al_{0.06}Ga_{0.940}As$ layer grown on an undoped GaAs buffer layer which in turn is grown on a [100] GaAs substrate. In this experiment the BTR condition requires a semiconductor laser with $E_0 = 1.476$ eV gain-switched at 98.8000050 MHz with pulses of 200 ps as a probe beam and a frequency doubled Nd:YAG laser mode locked at 98.8 MHz with pulses of 100 ps as a pump beam. Applying the double modulation technique the pump and probe beams were also modulated at 3 kHz and 177 Hz respectively and a *filter lock-in* was used with a time constant of 1 ms. Scanning the temperature from 270 to 370 K modifies, by the Varshini relation[7], the energy gap trom 1.50 to 1.46 eV. Despite the unfavorable conditions the $\Delta\mathbf{R}/\mathbf{R}\times E_g/E_0$ spectrum was measured successfully as shown at Fig. 3. As expected, the curve of Fig. 3 has the derivative line shape of PR measurements. And, as mentioned before, this plot is the same as the one obtained by conventional PR experiments. It is, to the authors knowledge, the first time that a double modulation technique is used to obtain PR spectra. The double modulation made also possible the assessment, on the reflection mode, of important parameters for carrier dynamics such as electron capture times by surface states[6].

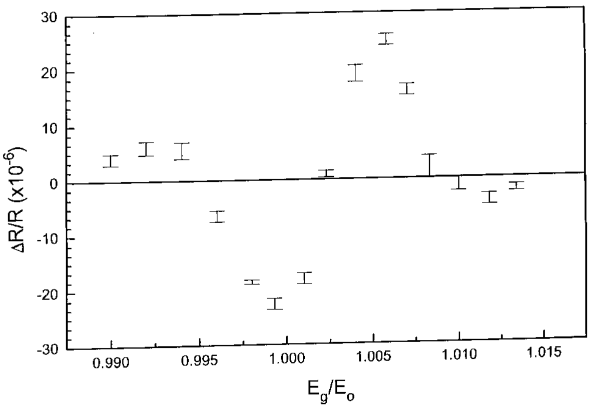

Figure 3. $\Delta\mathbf{R}/\mathbf{R} \times E_g/E_0$ using the double modulation technique.

IV. Conclusion

In summary, even at low probe intensity and with a PL varying signal it was possible to perform $\Delta\mathbf{R}/\mathbf{R} \times E_g/E_0$ measurements. This could be achieved due to the novel and simple technique of double modulation used for the PR measurement. This technique makes the PR spectrum free from undesirable signals in a straight forward way. In addition, this novel technique allowed the development of the BTR experiment which time resolves $\Delta\mathbf{R}$. The time resolved $\Delta\mathbf{R}$ data revealed important parameters for carrier dynamics.

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